US006328425B1

(12) **United States Patent**
Silverbrook

(10) **Patent No.: US 6,328,425 B1**
(45) **Date of Patent: Dec. 11, 2001**

(54) **THERMAL BEND ACTUATOR FOR A MICRO ELECTRO-MECHANICAL DEVICE**

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(73) Assignee: **Silverbrook Research Pty Ltd**, Balmain (AU)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/575,126**

(22) Filed: **May 23, 2000**

(30) **Foreign Application Priority Data**

Jun. 30, 1999 (AU) 99/1307

(51) **Int. Cl.**[7] **B41J 2/04**; B41J 2/135
(52) **U.S. Cl.** **347/54**; 347/44
(58) **Field of Search** 347/20, 44, 47, 347/54, 65, 67; 251/129.01, 30.01, 30.03, 84, 295; 60/528, 529; 310/307, 330, 331, 343

(56) **References Cited**

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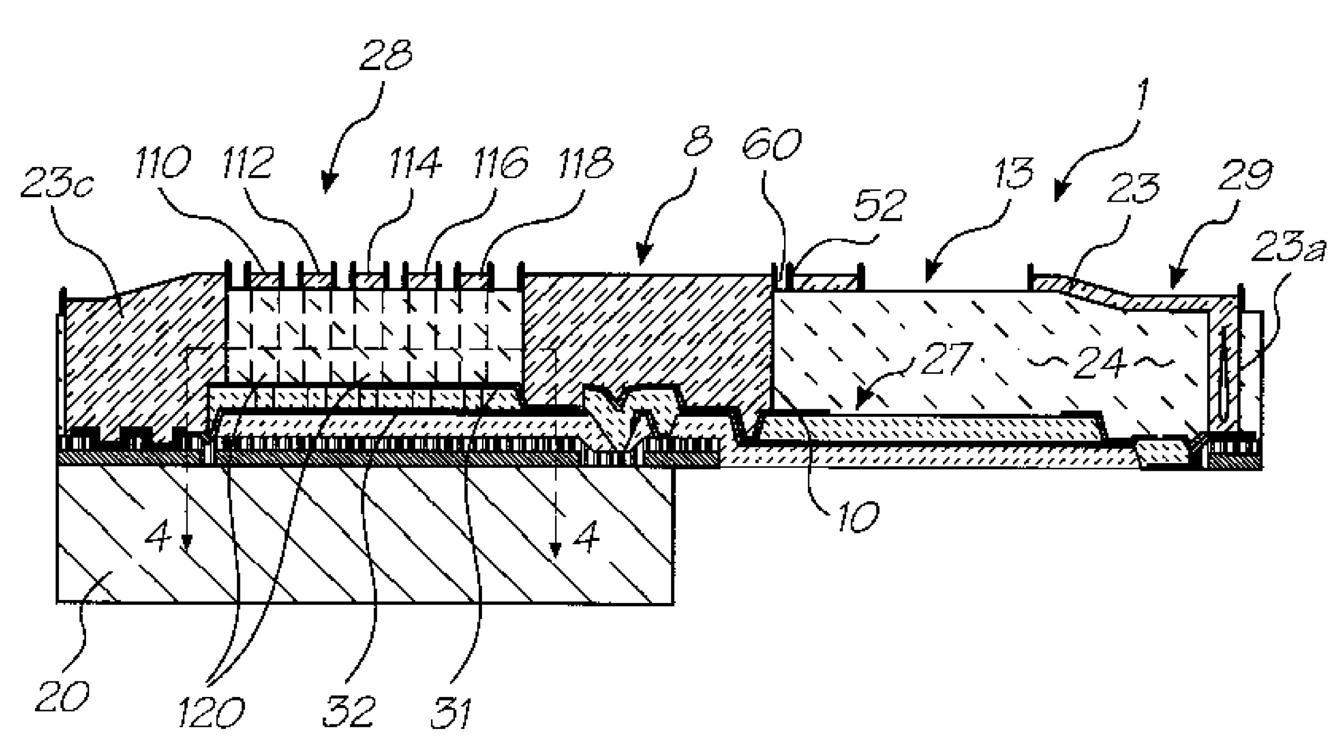
412 221 A2 2/1991 (EP) G11B/21/02
848 265 A2 6/1998 (EP) G02B/1/00

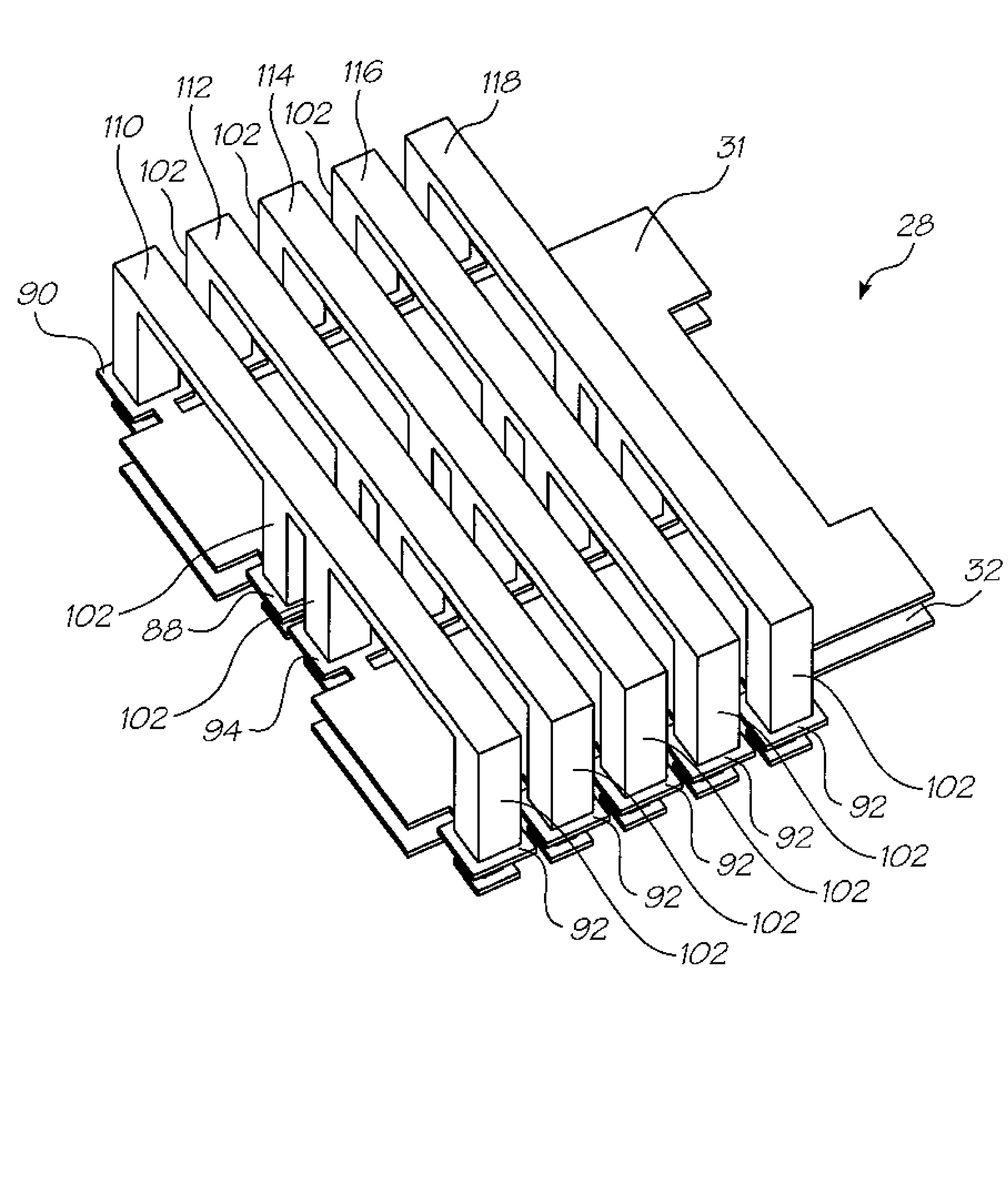
Primary Examiner—John Barlow
Assistant Examiner—Juanita Stephens

(57) **ABSTRACT**

A micro electro-mechanical device embodied within an ink ejection nozzle having an actuating arm that is caused to move an ink displacing paddle when heat inducing electric current is passed through the actuating arm is disclosed. The paddle is located in an ink chamber and the actuating arm passes through an actuator aperture in the chamber. The actuating arm has an inner arm and an outer arm and electrical current is supplied to the inner arm to cause bending of the actuating arm so as to move the paddle to eject a droplet of ink from the ink chamber. To prevent spurious bending modes and to force the actuating arm to undergo a desired bending mode so that the paddle moves appropriately to eject the ink droplet, the actuating arm includes connecting rods which connect side edges of the inner and outer arms and torsion bars which connect the connecting rods. The torsion bars and connecting rods reduce the likelihood of unwanted bending modes taking place which may effect the expulsion of an ink droplet from the chamber.

18 Claims, 4 Drawing Sheets





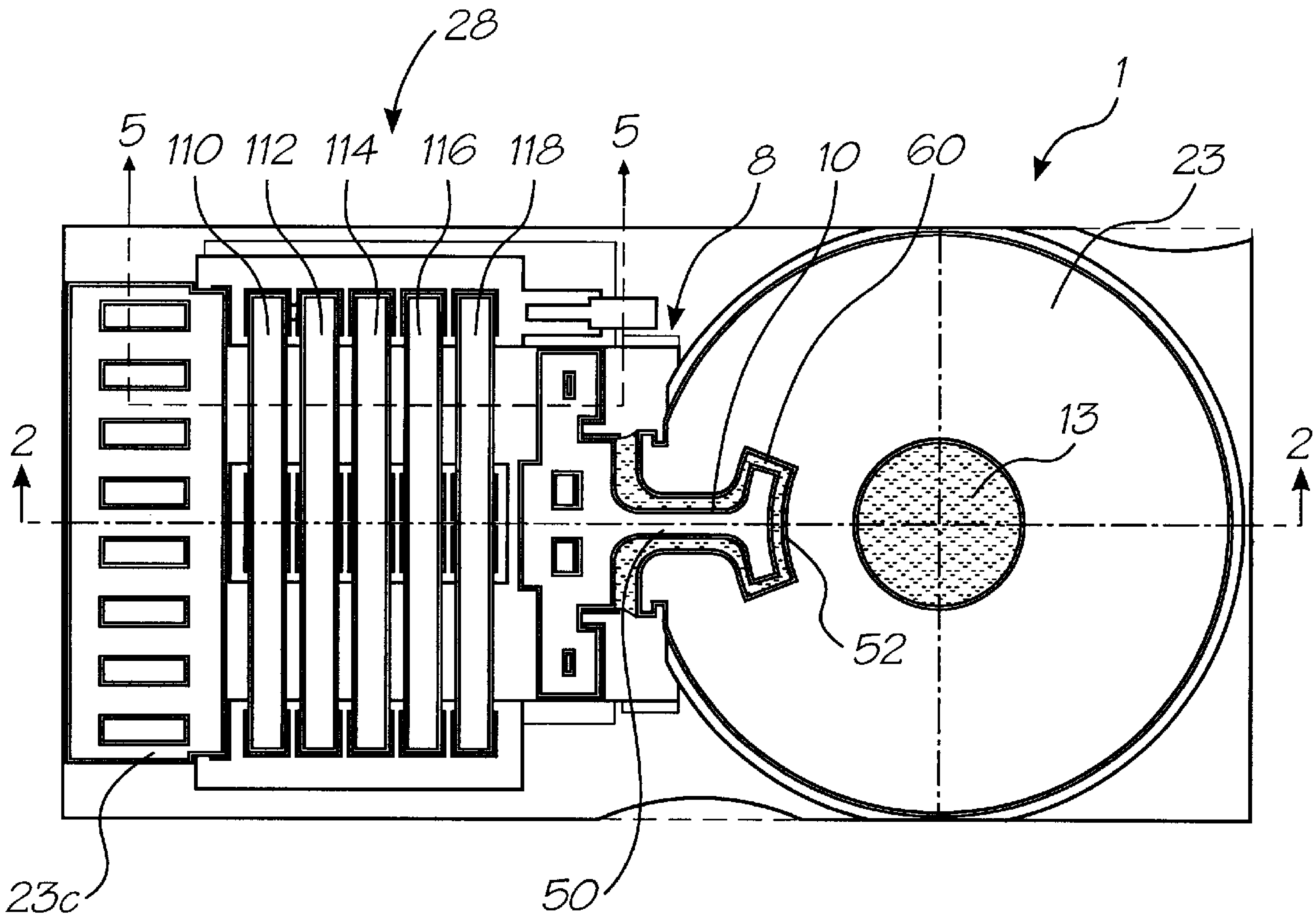
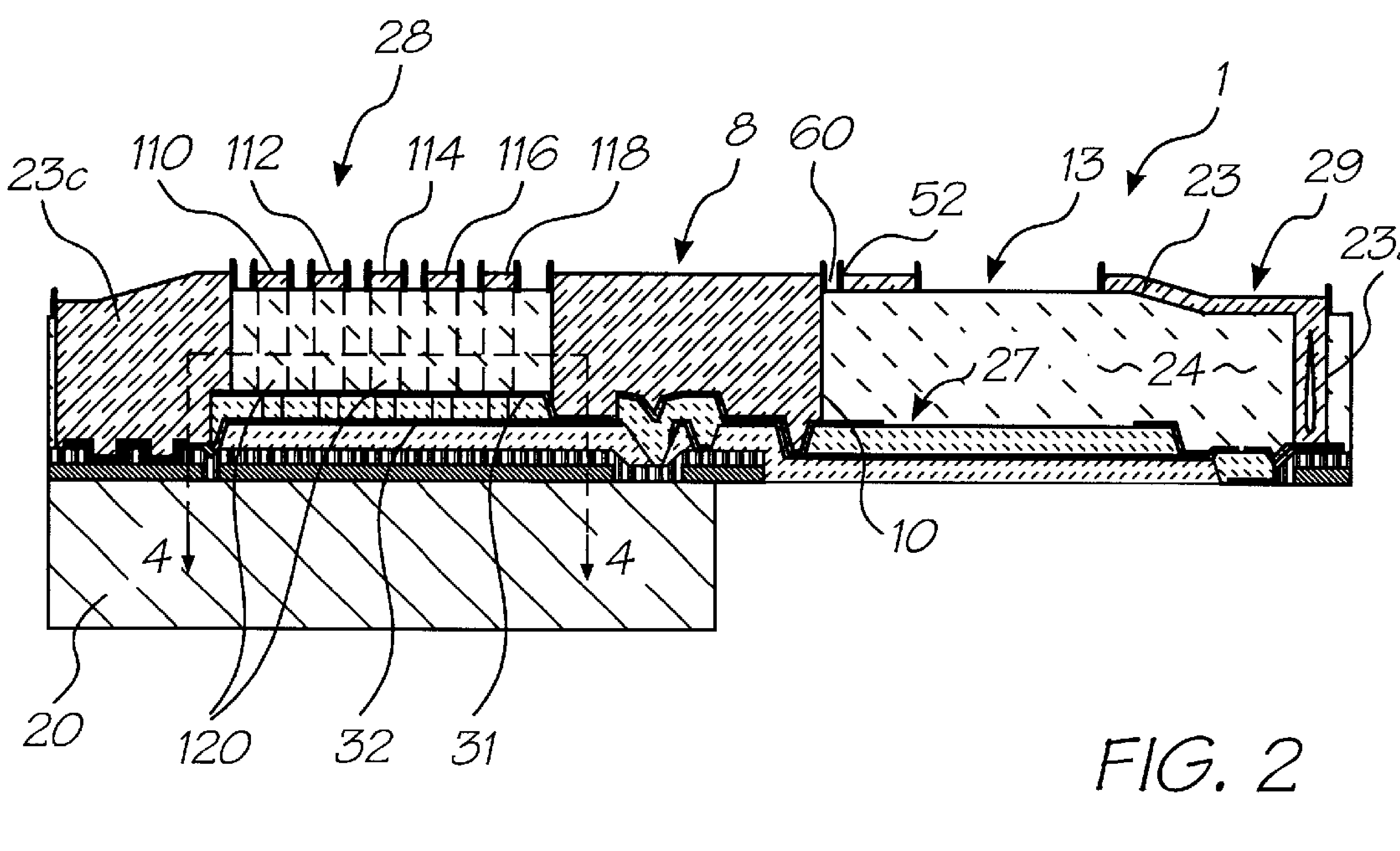

28
5
110
112
114
116
118
5
8
10
60
1
23
13
2
2
52
23c
50

FIG. 1


28
23c
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112
114
116
118
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60
52
13
1
23
29
23a
27
24
10
4
4
20
120
32
31

FIG. 2

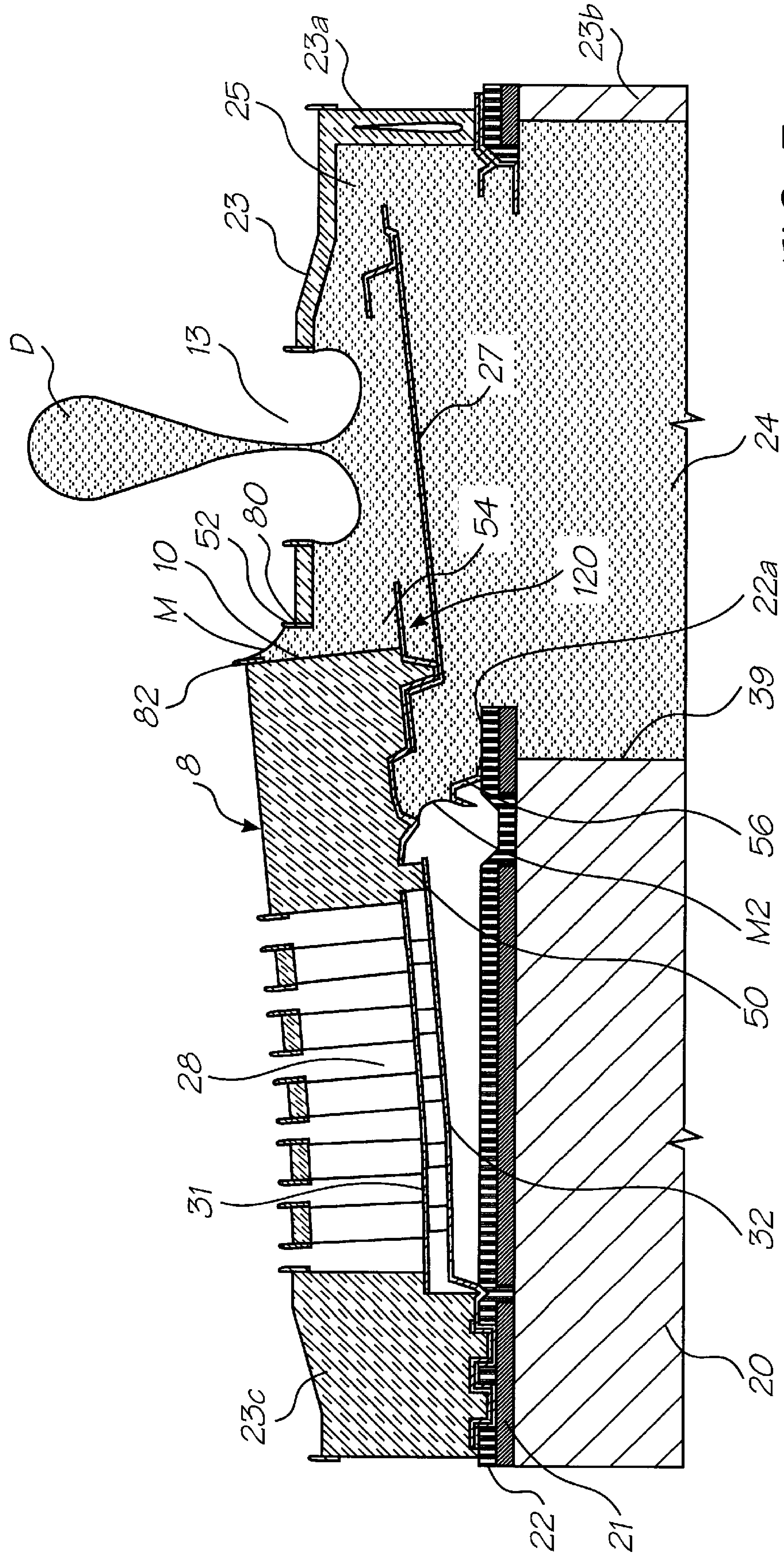
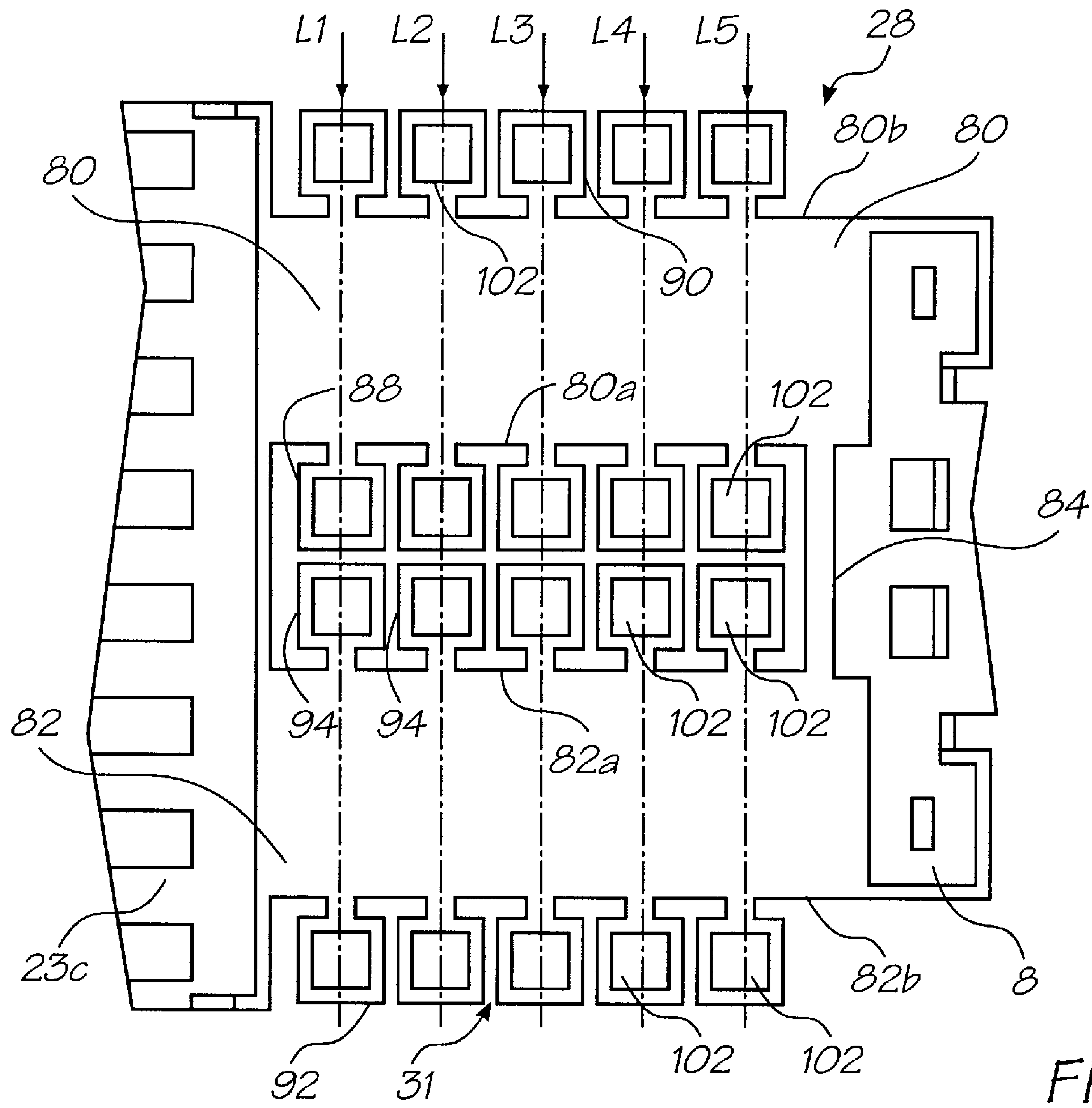
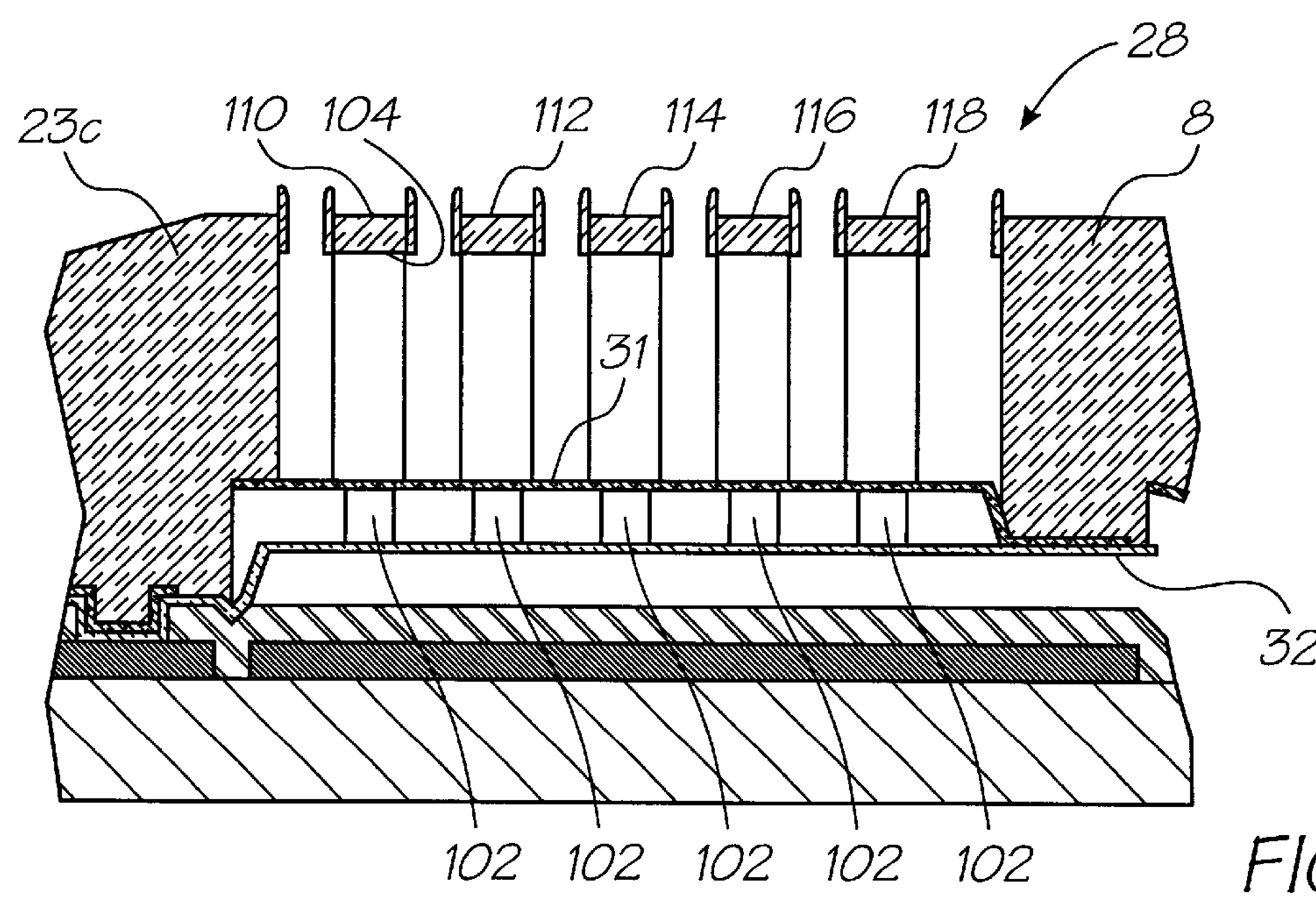

23a
23b
25
23
D
13
27
24
54
80
52
10
M
120
22a
82
39
8
56
M2
50
28
31
32
23c
20
22
21

FIG. 3



L1
L2
L3
L4
L5
28
80b
80
80
102
90
88
80a
102
84
82
94
94
82a
102
102
82b
8
23c
92
31
102
102

FIG. 4



28
23c
110
104
112
114
116
118
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32
102
102
102
102
102

FIG. 5

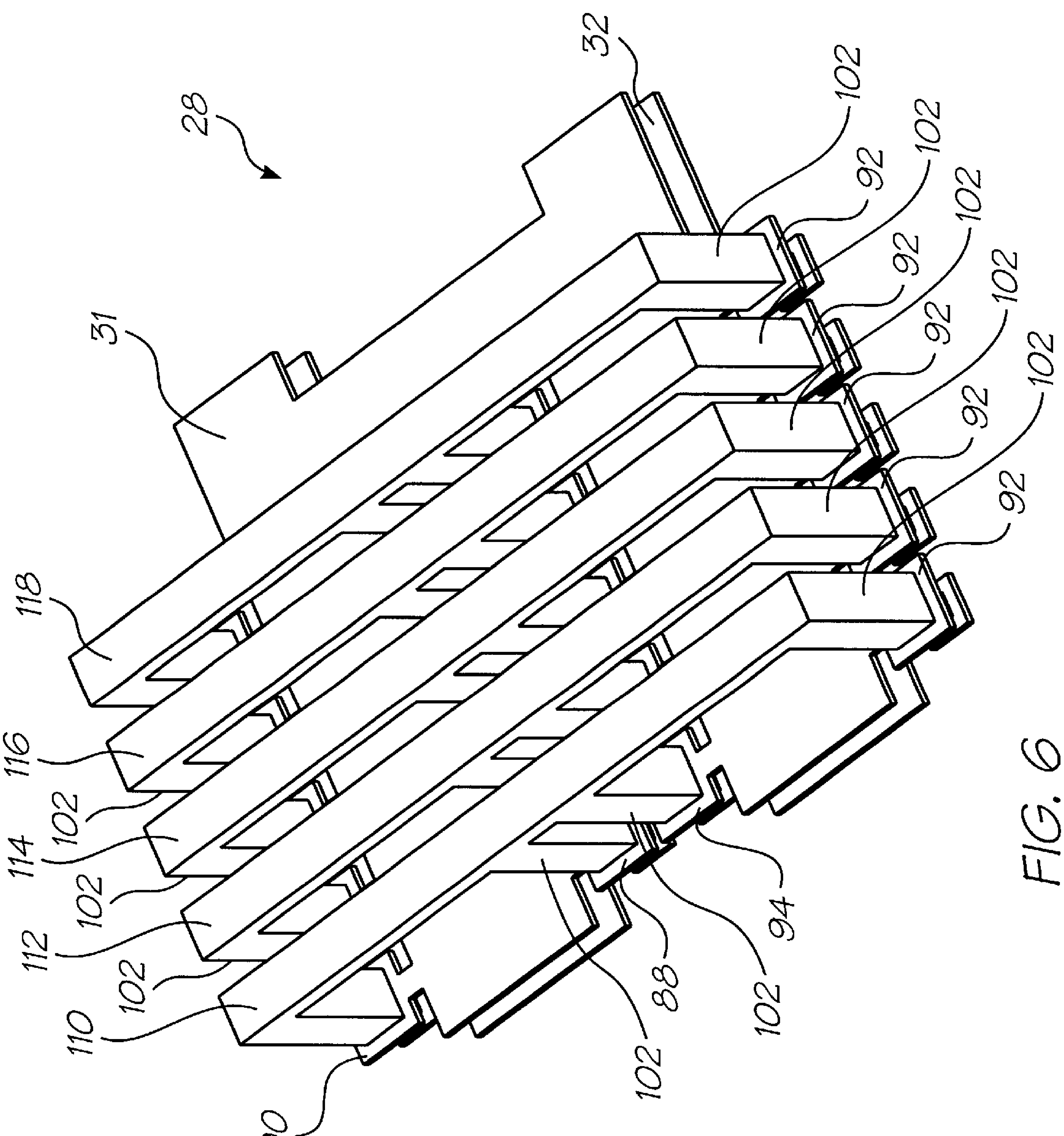

FIG. 6

THERMAL BEND ACTUATOR FOR A MICRO ELECTRO-MECHANICAL DEVICE

FIELD OF THE INVENTION

This invention relates to a thermal bend actuator for a micro electro-mechanical (MEM) device. The invention has application in ejection nozzles of the type that are fabricated by integrating the technologies applicable to micro electro-mechanical systems (MEMS) and complimentary metal-oxide semiconductor ("CMOS") integrated circuits, and the invention is hereinafter described in the context of that application. However, it will be understood that the invention does have broader application, to thermal bend actuators within other types of MEM devices.

CO-PENDING APPLICATIONS

Various methods, systems and apparatus relating to the present invention are disclosed in the following co-pending applications filed by the applicant or assignee of the present invention simultaneously with the present application:

NPA001US, NPA002US, NPA003US, NPA004US, NPA005US, NPA006US, NPA007US, NPA008US, NPA009US, NPA010US, NPA012US, NPA016US, NPA017US, NPA018US, NPA019US, NPA020US, NPA021US, NPA030US, NPA035US, NPA048US, NPA050US, NPA051US, NPA052US, NPA075US, NPB001US, NPB002US, NPK002US, NPK003US, NPK004US, NPK005US, NPK007US, NPM001US, NPM002US, NPM003US, NPM004US, NPN001US, NPN002US, NPN003US, NPP001US, NPP002US, NPP003US, NPP005US, NPP006US, NPP007US, NPP008US, NPP016US, NPP017US, NPP018US, NPP019US, NPS001US, NPS003US, NPS020US, NPT001US, NPT002US, NPT003US, NPT004US, NPX001US, NPX003US, NPX008US, NPX011US, NPX014US, NPX016US, NPX020US, NPX022US, IJ52US, IJM52US, MJ10US, MJ11US, MJ12US, MJ13US, MJ14US, MJ15US, MJ34US, MJ47US, MJ52US, MJ58US, MJ62US, MJ63US, MJ64US, MJ65US, MJ66US, PAK04US, PAK05US, PAK06US, PAK07US, PAK08US, PEC01US, PEC02US, PP01US, PP02US, PP03US, PP04US, PP07US, PP08US, PP09US, PP10US, PP11US, PP12US, PP13US, PP14US, PP15US, PP16US, PP17US.

The disclosures of these co-pending applications are incorporated herein by cross-reference. Each application is temporarily identified by its docket number. This will be replaced by the corresponding USSN when available.

BACKGROUND OF THE INVENTION

A high speed page width ink jet printer has recently been developed by the present applicant. This typically employs in the order of 51, 200 ink jet nozzles to print on **A4** size paper to provide photographic quality image printing at 1,600 dpi. In order to achieve this nozzle density, the nozzles are fabricated by integrating MEMS-CMOS technology and in this context reference may be made to International Patent Application No.PCT/AU00/00338 lodged by the present Applicant and entitled "Thermal Actuator".

These high speed page width ink jet printers produce an image on a sheet by causing a thermal bend actuator arm to move relative to a substrate by forming the actuating arm in part from an electrically resistive material and by applying a current to the arm to effect movement of the arm. The arm is connected to a paddle so that upon movement of the arm the paddle is moved to eject a droplet of ink onto the sheet. In order to eject the droplet of ink the paddle extends into a nozzle chamber which has a nozzle aperture, and movement of the paddle causes the droplet to be ejected from the nozzle aperture. The actuating arm is fixed at one end and when current is applied to the arm the arm is caused to bend to, in turn, move the paddle so as to eject the droplet from the nozzle aperture. In order for the paddle to move properly, so as to eject the droplet, the actuating arm is required to bend upwardly and generally pivot around the fixed end of the arm. Bending of the arm is caused by the application of an electrical current to the arm which causes an elongation of part of the arm relative to another part of the arm. To ensure that the actuating arm bends properly it is necessary to control bending modes of the arm which may result in improper movement of the paddle which may effect the ejection of a droplet from the nozzle chamber. For example, the elongation of one part of the arm relative to the other can cause the arm, rather than to bend upwardly as required, to curl up at the sides forming a general dish shaped configuration, or bend into a sinusoidal configuration or other curved configuration. These bending modes may result in improper movement of the paddle which, as noted above, may effect the manner in which a droplet is ejected from the nozzle chamber.

SUMMARY OF THE INVENTION

A first aspect of the invention provides a thermal bend actuator for a micro electro-mechanical device comprising:

- a first actuator portion,
- a second actuator portion spaced from the first actuator portion, the second actuator portion being conductively heatable to cause bending of the thermal bend actuator,
- a first connecting member interconnecting the first and second portions,
- a second connecting member interconnecting the first and second portions, and
- a torsion member coupled to and interconnecting the first and second connecting members.

Thus, according to this aspect of the invention, the provision of the connecting portions which interconnect the actuator portions and the torsion member which interconnects the connecting portions, reduce the bending modes which are likely to occur upon thermal heating of the thermal bend actuator thereby forcing the actuator to bend according to the desired mode to ensure proper movement of the thermal bend actuator.

The invention may also be said to reside in a micro electro-mechanical device comprising:

- a fluid chamber for containing a fluid,
- an outlet in the chamber for allowing exit of fluid from the chamber,
- a thermal bend actuator for dispensing fluid from the chamber through the outlet aperture, the thermal bend actuator having
  - a first actuator portion,
  - a second actuator portion spaced from the first actuator portion and being conductively heatable to cause bending of the thermal bend actuator,
  - a first connecting member interconnecting the first and second portions,
  - a second connecting member interconnecting the first and second portions, and
  - a torsion member coupled to and interconnecting the first and second connecting members.

PREFERRED FEATURES OF THE INVENTION

Preferably each actuator portion has at least two spaced apart fingers, said first connecting member interconnecting first fingers of the first and second actuator portions, and the second connecting member interconnecting second fingers of the first and second actuator portions.

Preferably each finger is provided with a tab and the respective connecting member is coupled to the tab of each finger.

Preferably each finger has a first edge and a second edge and a plurality of tabs are provided on the first edge and second edge of each finger, and the connecting members extend between a respective one of the tabs on the fingers of the first actuator portion and a respective one of the tabs on the fingers of the second actuator portion.

Preferably the connecting members extend through the tabs of one of the actuator portions and have ends which are spaced from the said one of the actuator portions, and a said torsion member interconnects the ends of respective pairs of the connecting members.

Preferably the connecting members comprise connecting rods.

Preferably the torsion members comprise torsion bars.

Preferably the thermal actuator includes a paddle located in the chamber and moveable upon bending of the thermal actuator to eject a droplet of liquid from the chamber through the nozzle aperture.

Preferably the chamber has an upper wall and the torsion member is formed by deposition simultaneously with the upper wall of the chamber.

Preferably the torsion members are formed by deposition by first forming an opening in the tabs provided on one of the actuator portions and depositing material so that the material is deposited through the openings and onto the tabs associated with the other of the first or second actuator portions so as to interconnect the actuator portions, the material being deposited to form the connection members so that the connection members have free ends substantially level with the upper wall of the chamber.

Preferably the connecting members are provided intermediate ends of the thermal bend actuator.

BRIEF DESCRIPTION OF THE DRAWINGS

A preferred embodiment of the invention will be described, by way of example, with reference to the accompanying drawings in which;

FIG. **1** is a plan view of one embodiment of the invention in an ink jet nozzle for a printer;

FIG. **2** is a cross-sectional view along the line **2**—**2** of FIG. **1**;

FIG. **3** is a cross-sectional view similar to FIG. **2** showing more detail and with the device in an extreme actuated position showing a drop being ejected from the nozzle;

FIG. **4** is a view along the line **4**—**4** of FIG. **2**;

FIG. **5** is a view along the line **5**—**5** of FIG. **1**; and

FIG. **6** is a perspective view of a thermal bend actuator according to the preferred embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As illustrated with approximately 3000× magnification in FIG. **1**, and other relevant drawing Figures, a single ink jet nozzle device **1** is shown as a portion of a chip which is fabricated by integrating MEMS and CMOS technologies. The complete nozzle device includes a support structure having a silicon substrate **20**, a metal oxide semiconductor layer **21**, a passivation layer **22**, and a non-corrosive dielectric coating/chamber defining layer **29**. Reference may be made to the above identified International Patent Application No. PCT/AU00/001338 for disclosure of the fabrication of the nozzle device. Operation of the device is also more fully disclosed in co-pending application entitled "Movement Sensor In A Micro Electro-mechanical Device" (MJ12) by the same applicant. The contents of these two applications are incorporated into this specification by this reference.

The nozzle device incorporates an ink chamber **24** which is connected to a source (not shown) of ink. The layer **29** forms, amongst other components as will be described hereinafter, a chamber wall **23** which has a nozzle aperture **13** for the ejection of a droplet from ink **25** contained within the chamber **24**. As best shown in FIG. **1** the wall **23** is generally cylindrical in configuration with the aperture **13** being provided substantially in the middle of the cylindrical wall **23**. The wall **23** has a part circular concave edge portion which forms part of the periphery of the wall **23**.

As best seen in FIG. **3**, the chamber **24** is also defined by a peripheral side wall **23***a*, a lower side wall **23***b*, a base wall (not shown), and by an edge portion **39** of substrate **20**. An actuating arm **28** (shown schematically in FIG. **3** and in detail in FIGS. **4**–**6**) is formed on layer **22** and support portion **23***c* is formed at one end of the actuating arm **28**.

The actuating arm **28** is deposited during fabrication of the device and is pivotable with respect to the substrate **20** and support **23***c*. The actuating arm **28** comprises upper and lower arm portions **31** and **32**. Lower portion **32** of the arm **28** is an electrical contact with the CMOS layer **21** for the supply of electrical current to the portion **32** to cause movement of the arm **28**, by thermal bending, from the position shown in FIG. **2** to the position shown in FIG. **3** so as to eject droplet D through aperture **13** for deposition on a sheet (not shown). The layer **22** therefore includes the power supply circuitry for supplying current to the portion **32** together with other circuitry for operating the nozzle shown in the drawings as described in the aforesaid co-pending applications.

A block **8** is mounted on the actuator arm **28**. The actuator **28** carries a paddle **27** which is arranged within the chamber **24** and which is moveable with the actuator as shown in FIGS. **1** and **3** to eject the droplet D.

The peripheral wall **23***a*, chamber wall **23**, block **8** and support portion **23***c* are all formed by deposition of material which forms the layer **29** and by etching sacrificial material to define the chamber **24**, nozzle aperture **13**, the discrete block **8** and the space between the block **8** and the support portion **23***c*. The lower wall portion **23***b* is also formed during deposition with the substrate **20**.

The block **8** includes a generally T-shaped portion **50** (when viewed in plan) which has a peripheral wall **10**. The upper wall **23** of the chamber **24** has a generally T-shaped slot **60**, defined by edge portion **52** of the wall **23**, which receives the T-shaped portion **50** of the block **8**. The actuator **28** carries a paddle **27** which is arranged within the chamber **24** and which is moveable with the actuator as shown in FIGS. **1** and **3** to eject the droplet D.

The space between end edge **22***a* of layer **22** and edge portion **50** of the wall **23** defines an actuator aperture **54** which is substantially entirely closed by T-shaped portion **50** of the block **8** when the actuator **28** is in a rest or quiescent state as shown in FIGS. **1** and **2**. In the quiescent position shown in FIGS. **1** and **2**, the wall **10** of the portion **50** is separated from the edge **52** by a distance of less than one micron so as to define a fine slot between the edge **52** and the wall **10**.

As the actuator arm **28** moves up and down to eject droplet D from the chamber **15 24**, the block **8** and wall **10** move up and down relative to edge **52** of slot **60** of the wall **23** whilst maintaining a closely spaced apart relationship with the edge **52** of the wall **23**. A meniscus M is formed between the wall **10** and the edge **52** as the wall **10** moves up and down relative to the edge **57** in view of the close proximity of the wall **10** to the edge **52**. The maintenance of the meniscus M, forms a seal between edge **52** and wall **10**, and therefore reduces opportunities for ink leakage and wicking from chamber **24**. A meniscus M2 is also formed between support flange **56** formed on the layer **22** and portion **58** of the actuator **28** on which block **8** is formed. When in the quiescent position the portion **58** rests on the flange **56**. The formation of the meniscus M2 also reduces opportunities for ink leakage and wicking during movement of the actuating arm **28** and the paddle **27**. A meniscus (not shown) is also formed between the sides (not shown) of actuator aperture **54** and the edges (not shown) of wall **23***a* which define the aperture **54**.

As shown in FIG. **3**, the edge portion **10** may carry a lip **80** and the wall **9** may also carry a lip **82** to further reduce the likelihood of wicking of ink from the chamber **24** onto the block **8** or upper surface of the wall **23**. The lip **80** may extend completely about the periphery of the wall **23** and similar lips may also be provided on the aperture **13**.

With reference to FIGS. **4** to **6**, the thermal bend actuator **28** is shown in detail. In FIG. **6** the block **8** and the support portion **23***c* are not shown for ease of illustration and to show as much detail as possible in FIG. **6** of the actuator arm **28**.

The actuator arm includes the lower arm **32** and the upper arm **31** previously described. As best shown in FIG. **4**, the lower arm **32** and the upper arm **31** both comprise a first finger **80** and a second finger **82** which are joined by a base section **84**. The ends of the fingers **80** and **82** remote from the base section **84** are secured in support structure **23***c* so that the arm **28** can pivot relative to the support structure **23***c* as shown in FIG. **3**. The fingers **80** and **82** have side edges **80***a* and **80***b* and **82***a* and **82***b* respectively. The side edges **80***a*, **80***b*, **82***a* and **82***b* have integral tabs or staples **88**, **90**, **92** and **94** respectively. As shown in FIG. **4**, five such tabs are provided on each of the side edges **80***a*, **80***b*, **82***a* and **82***b*.

The tabs on the arm **31** are formed integral with the remainder of the arm **31** when the arm **31** is deposited. The lower arm **32** is identical to the arm **31** as described above and is arranged below the upper arm **31** as clearly shown in FIGS. **2**, **3**, **5** and **6**.

The tabs **88**, **90**, **92** and **94** in upper arm **31** are provided with circular holes **100**. The holes **100** are formed by masking and depositing sacrificial material within the tabs **88–94** and then etching away the sacrificial material to leave holes **100** passing through the tabs **88** to **92**. Rods **102** are deposited so as to extend from tabs **88–92** (not shown) on lower arm **32** through the holes **100** in tabs **88–92** of the upper arm **31**. The rods **102** have a free end **104** which is substantially at the same level as the upper wall **23** of the chamber **24** when the arm **28** is in its quiescent position shown in FIGS. **1** and **2**. Thus, the tab **92** on the arm **32** is interconnected with the tab **92** on the arm **31** which is immediately above the tab on the arm **32**. Each of the tabs **88**, **90**, **92** and **94** of the respective arms **31** and **32** are connected by rods **102** in the same manner.

As will be apparent from a consideration of FIGS. **4** to **6**, five sets of rods **102** are therefore provided with each set containing four rods **102** which are in alignment as shown by lines labelled L1 to L5 in FIG. **4**. The posts **102** in line L1 are interconnected at their free ends **104** by a torsion rod **110**. The posts in line L2 are interconnected by a torsion rod **112**. The posts in line **13** are interconnected by a torsion rod **114**. The posts in line L4 are interconnected by a torsion rod **116** and the posts in line L5 are interconnected by a torsion rod **118**. The torsion rods **110–118** may be deposited at the same time as the layer **29** from which the upper wall **23**, block **8** and support structure **23***c* is formed. The torsion bars **110** to **118** therefore interconnect the sides of the fingers **82** and **80** and prevent the side edges from curling or cusping upwardly so that the actuator arms would form a dish shape or valley type shape upon application of current to the arm **32**. Hence the torsion bars **110** to **118** reduce the opportunity for any cusping of the thermal bend actuator during operation and reduce the number of bending modes which are possible upon heating of the actuator arm **32**. This tends to force the arm to bend only in the manner shown in FIG. **3** so as the paddle is moved in the proper manner to properly eject a droplet D from the nozzle aperture **13**.

The provision of five posts on each edge of the fingers **80***a* to **82***b* also ensures that the likelihood of the arms bending into a sinusoidal or wave like shape is prevented. The torsion rods **110** to **118** therefore tie the two edges of the arms **31** and **32** together and in particular the side edges of the fingers **88** to **94** together thereby preventing the cusping or bowing of the actuator arm and the plural number of posts **102** arranged along the edges **80***a* to **80***b* of intermediate the ends of the fingers **80** and **82** further reduces the possible bending modes by reducing the likelihood of the arms bending into a sinusoidal or wave like shape.

I claim:

1. A thermal bend actuator for a micro electro-mechanical device comprising:

a first actuator portion,

a second actuator portion spaced from the first actuator portion and being conductively heatable to cause bending of the thermal bend actuator,

a first connecting member interconnecting the first and second portions,

a second connecting member interconnecting the first and second portions, and

a torsion member coupled to and interconnecting the first and second connecting members.

2. The actuator of claim **1** wherein each actuator portion has at least two spaced apart fingers, said first connecting member interconnecting first fingers of the first and second actuator portions, and the second connecting member interconnecting second fingers of the first and second actuator portions.

3. The actuator of claim **1** wherein the connecting members comprise connecting rods.

4. The actuator of claim **1** wherein the torsion members comprise torsion bars.

5. The actuator of claim **2** wherein each finger is provided with a tab and the respective connecting member is coupled to the tab of each finger.

6. The actuator of claim **5** wherein each finger has a first edge and a second edge, and a plurality of tabs are provided on the first edge and second edge of each finger, and the connecting members extend between a respective one of the tabs on the fingers of the first actuator portion and a respective one of the tabs on the fingers of the second actuator portion.

7. The actuator of claim **6** wherein the connecting members extend through the tabs of one of the actuator portions and have ends which are spaced from the said one of the actuator portions, and a said torsion member interconnecting the ends of respective pairs of the connecting members.

8. A micro electro-mechanical device comprising:

a fluid chamber for containing a fluid,

an outlet in the chamber for allowing exit of fluid from the chamber,

a thermal bend actuator for dispensing fluid from the chamber through the outlet aperture, the thermal bend actuator having

a first actuator portion,

a second actuator portion spaced from the first actuator portion and being conductively heatable to cause bending of the thermal bend actuator,

a first connecting member interconnecting the first and second portions,

a second connecting member interconnecting the first and second portions, and

a torsion member coupled to and interconnecting the first and second connecting members.

9. The device of claim **8** wherein each actuator portion has at least two spaced apart fingers, said first connecting member interconnecting first fingers of the first and second actuator portions, and the second connecting member interconnecting second fingers of the; first and second actuator portions.

10. The device of claim **8** wherein the connecting members comprise connecting rods.

11. The device of claim **8** wherein the torsion members comprise torsion bars.

12. The device of claim **8** wherein the thermal actuator includes a paddle located in the chamber and moveable upon bending of the thermal actuator to eject a droplet of liquid from the chamber through the nozzle aperture.

13. The device of claim **8** wherein the chamber has an upper wall and the torsion member is formed by deposition simultaneously with the upper wall of the chamber.

14. The device of claim **8** wherein the connecting members are provided intermediate ends of the thermal bend actuator.

15. The device of claim **9** wherein each finger is provided with a tab and the respective connecting member is coupled to the tab of each finger.

16. The device of claim **15** wherein each finger has a first edge and a second edge, and a plurality of tabs are provided on the first edge and second edge of each finger, and the connecting members extend between a respective one of the tabs on the fingers of the first actuator portion and a respective one of the tabs on the fingers of the second actuator portion.

17. The device of claim **16** wherein the connecting members extend through the tabs of one of the actuator portions and have ends which are spaced from the said one of the actuator portions, and a said torsion member interconnecting the ends of respective pairs of the connecting members.

18. The device of claim **17** wherein the connecting members are formed by deposition by first forming an opening in the tabs provided on one of the actuator portions and depositing material so that the material is deposited through the opening and onto the tabs associated with the other of the first or second actuator portions so as to interconnect the actuator portions, the material being deposited to form the connection members so that the connection members have a free end substantially level with the upper wall of the chamber.

* * * * *